Chapter

High Density Planting System of Cotton in India: Status and Breeding Strategies

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Abstract

Cotton, a crop of choice, occupies the second premier position next to food crops in providing clothing. Though 53 species of Gossypium are available, only four species are cultivable and among the four, the major cultivable area falls under *G. hirsutum*. Though varieties with medium, superior medium, long and extra long staple cotton were released earlier, with the advent of machineries, ginning facilities, mills were literally requiring cotton fiber of any length. With the advent of Bt technology and the release of hybrids during 2002, cotton productivity had a momentum. However, considering the duration, cost involved in manual harvesting etc., farmers were looking for alternate option and High Density Planting System (HDPS) offered a promise in this direction. Farmers were looking for genotypes that could yield better under higher planting densities with fewer bolls per plant, synchronized maturity with uniform bursting. Efforts have been taken all over the World in this direction and India is not an exception. Handful of varieties fitting to this situation has been released from many of the Universities. This chapter essentially summarizes the genetic, agronomic, plant protection interventions and the futuristic requirements for achieving at least 700 kg of lint per hectare.

Keywords: cotton, compact, ideal genotypes, high density planting system, genetic interventions

1. Introduction

Cotton (*Gossypium hirsutum* L.) is the major fiber and cash crop, not only in India but for the entirety. Cotton is the only crop which travels with the human being in each and every part of his/her life. It is cultivated in tropical as well as sub-tropical regions of more than seventy countries of the World. Cotton is a crop of global significance playing a significant role in the agricultural and industrial economy. Around 60% of fiber to Indian textiles is from cotton. The recent statistics released from USDA - Foreign Agricultural Service (September 2020) indicates that India (13.40 million ha) has more than one third of the World's area (32.94 million ha) under cotton with a productivity of 487 kg/ha, which is far below than the World's productivity of 775 kg/ha. Many of the Countries like Brazil, China, Turkey, Australia have the productivity of more than

1500 kg/ha. China with 3.25 million ha of cultivation (less than one fourth of the area of India) could result in a production of 27.25 million 480 lb. bales (as projected by USDA) compared to the Indian production projected at 30.00 million 480 lb. bales from 13.40 million ha. This clearly signifies the productivity gap prevailing at India for cotton.

If Indian production is juxtaposed against China during 2019/20 marketing year, China accounted for just over 22 percent of total world cotton production, of which 86 percent of that was produced in Xinjiang province (just under 20 percent of the world total). China exports only a small amount of cotton lint, half-of-one-percent of production. Other than some minor exports to North Korea, China is the world's largest importer of cotton. This provides China with a supply of cotton normally greater than one-third of world use and nearly 40 percent larger than India [1]. This scenario also clearly explains the gap which is existing in India compared to other Countries which could make the country to progress further in the yield front of cotton provided newer technologies and cropping systems are adopted *in toto*.

2. Indian cotton scenario

About 59 per cent of the raw material requirement of the Indian textile industry is met by cotton. It plays a major role in sustaining the livelihood of An estimated 5.8 million cotton farmers' livelihood is sustained by cultivating cotton. Besides, this crop engages 40–50 million people in one or the other related activities. As seen, the area under cotton in India is also tremendous which is around 13.40 million hectares. Among the 53 species of *Gossypium* available, Indians cultivate all the four species of cotton namely *Gossypium arboreum* and *herbaceum* (Asiatic cotton), *G. barbadense* (Egyptian cotton) and *G. hirsutum* (American Upland cotton) with *G. hirsutum* being cultivated over the entire Country. It is about 88% of the hybrid cotton being cultivated in India belongs to *hirsutum* type and almost all the *Bt* cotton hybrids belong to G.*hirsutum* type.

Cotton is grown in all the three different agro-ecological zones of India *viz.*, Northern, Central and Southern zones. Nearly 70 percent of the crop is cultivated under rainfed condition in the Central and Southern regions of the country. Among the cotton producing states, Maharashtra is the largest producer with an area of 38.06 lakh ha followed by Gujarat (24 lakh ha) and Telangana (17.78 lakh ha). In India, the production of cotton is recorded in bales which are of 170 kg. The production is highest in Gujarat with 95 lakh bales followed by Maharashtra (89 lakh bales) and Telangana (59.50 lakh bales). Karnataka stands first in productivity with 769 kg ha^{-1} followed by Andhra Pradesh (719 kg ha^{-1}) and Rajasthan (692 kg ha^{-1}) [2].

Majority of the cotton produced in India is derived from nine major cotton growing states and these States fall under three diverse agro-ecological zones.

Northern Zone-Punjab	-	Haryana and Rajasthan.
Central Zone-Gujarat	-	Maharashtra and Madhya Pradesh.
Southern Zone-Telangana	-	Andhra Pradesh and Karnataka.

In addition, cotton is also grown in the States of Tamil Nadu and Odisha. Recently, cotton is also being cultivate in small scale in non-traditional States such as Uttar Pradesh, West Bengal, Tripura, etc. Nevertheless, India is the largest producer cum leading consumer of cotton in the World. It's very clear now that albeit having higher area under cotton, the productivity of cotton is very low compared to many of the Countries which warrants attention mainly on developing newer genotypes that would yield better on higher management condition. Strategies that could maximize the per unit area yield in cotton would include

- Developing ideotypes in cotton that would suit mechanized cultivation starting from sowing to lint collection
- Standardized agro-management systems for exploiting more unit area productivity
- Robust management procedures to ward off pests, diseases and other nutritional disorders and
- Assured price for quality produce

Primarily, the productivity enhancement in any crop depends on the development of suitable genotype and cotton is not an exception. Many of the wild species available in the crops are exploited for transferring the segments (QTLs) that harbor pests and diseases resistance *vis-a-vis* high yield. Though about 53 species of *Gossypium* are available including the four cultivated species, only very few diploid and tetraploid wild species of *Gossypium* are crossable with the cultivated species. Among the species of *Gossypium*, seven species are with AD genome measuring 2400 Mb genome size, three species with A genome (1700 Mb), four species with B genome (1350 Mb), three species in C genome (1980 Mb), 13 species with D genome (885 Mb), seven species in E genome (1560 Mb), one species belonging to F genome (1300 Mb), three species under G genome (1785 Mb) and 12 species under K genome (2570 Mb) [3]. Since cotton is being available in the field for more than 5–6 months before harvest, per day productivity of the crop also receives much attention.

Another statistical prediction provided by Dr. M. V. Venugopalan of CICR, Nagpur [4] is that the cotton productivity during 2018–2019 would be the lowest despite the fact that almost 90% of the farmers have adopted the state of art BG II hybrids. This had been exclusively due to the increase in cost of cotton cultivation from Rs. 2233/q of seed cotton in 2002–2003 to Rs.4803/q in 2015–2016, mainly due to increase in labour wages and increased use of inputs like fertilizers and pesticides. Considering these facts, primary aim of the plant breeders has to be in designing a genotype that would fit for the given situation.

Moreover, the present day hybrids put forth biomass enormously and are of speed and spread growing in nature. Thus, the ratio of bolls to biomass if worked out would be much lesser. For having a match between the growth, water requirement, duration, yield, per unit and day productivity etc. a system was arrived at by the Central Institute of Cotton Research, Nagpur which is High Density Planting System (HDPS) with early maturing, semi compact genotypes for realizing higher yields with low production costs under rainfed condition primarily. The main tenets of this proposition covers tailoring a genotype suiting to high density planting (more than one lakh plants per hectare), its uniformity in boll development, maturation and bursting, its adoptability to the given condition and efficiency in the nutrient utilization etc.

In the forth coming discussions, let us see about the genetic, agronomic and plant protective interventions that would help in developing a suitable genotype fitting to HDPS.

2.1 Genetic interventions

2.1.1 Genetic enhancement

The term "enhancement" was first used by [5] for defining the transfer of useful genes from exotic or wild types into agronomically acceptable background, preferably a cultivar of choice. This term of enhancement was later [6] rechristened as pre-breeding or developmental breeding to describe the same activity. Thus, having varied terminologies basically refer to the transfer or introgression of genes or gene combinations from unadapted sources, mostly the wild sources into the breeding materials, preferably an adapted background [7]. Normally, genetic enhancement is complementary to that of traditional breeding. However, these activities, as name suggests, form the base of any plant breeding programme where the gene transfer from wild species /related species is targeted. Thus enhanced germplasm can be more readily used in breeding programmes for cultivar development. Thus, pre-breeding qualifies as prior step of sustainable plant breeding which normally starts with identifying a useful character in unadapted or wild genotypes, capturing its genetic diversity and extracting the genes/QTLs that govern these variations for exploitation. Thus pre-bred materials may also be an intermediary with a value addition which could be further exploited.

Normally, wild species are exploited for transferring traits related to the improvement of yield, quality, pests and diseases resistance. In cotton, for altering the plant types, the wild species are not that much useful for the reasons that most of them are perennial with spreading habit. Hence, for breeding an ideal genotype with less/shy branching, zero monopodia, minimalistic bolls with uniform weight, luster, shape and bursting etc. which would also suit mechanized cultivation, exploring the available variability among the germplasm must be the pre-requisite.

Research on HDPS on cotton gained momentum under the leadership of ICAR – Central Institute for Cotton Research, Nagpur in 2010. Shortly thereafter, in 2012, the All India Coordinated Cotton Improvement Project (AICCIP, now AICRP on Cotton) started a separate trial on the evaluation of compact genotypes for HDPS under rainfed and irrigated situation to facilitate the release of compact genotypes suitable for HDPS. Variety CSH 3075 was the first cotton variety released for HDPS in India. [4]. Subsequently, research got momentum and Tamil Nadu Agricultural University (TNAU) has also released two varieties *i.e.,* TCH 1705 as CO 15 and TCH 1819 as CO 17 for HDPS. Cotton CO 17 has been performing well under rice fallow conditions of Cauvery Delta Zone of Tamil Nadu (**Figure 1**).

2.1.2 Varietal evaluation

A high yielding *G.hirsutum* variety CO 15 developed from Department of Cotton, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural

Figure 1.
HDPS cotton (CO 17) being cultivated at farmer's holding.

University, Coimbatore was evaluated in All India Coordinated Cotton Improvement Project trials on cotton during the year 2012–2013. This culture registered a significant seed cotton yield (2346 kg/ha) which is 111.2% increase over the local check Suraj (normal spacing) (1111 kg/ha). In south zonal trials, during 2013–2014, CO 15 (3582 kg/ha) out yielded the zonal check Suraj (3158 kg/ha) by 13.4% and stood at third place and during 2014–2015 registering 5.3% increased yield (2378 kg/ha) than the zonal check Suraj (2259 kg/ha). The seed cotton yield was maximum to the tune of 3226 kg/ha as against 2443 kg/ha of LH 2298 under.

60 x 10 cm. This culture is found to be fertilizer responsive in all the location. Increasing the spacing results yield loss in almost all the centres indicating its suitability for high density planting. It registered moderate resistance to Bacterial blight and Gray mildew. The overall performance (2012–2015) revealed its superiority in mean seed cotton yield (2807 kg/ha) as against the local check Suraj (normal spacing) (2146 kg/ha). The increase in kapas yield was 30.8% over local check. Besides high seed cotton yield, it possessed higher ginning out turn of 36.6% than zonal check Suraj (34.1%). This culture comes under the medium long staple category with 2.5% span length of 27.1 mm, fiber strength of 21.5 g/tex and micronaire value of 4.3. It can spin up to 30–40's counts.

Cotton variety CO 17 is a short duration compact plant type with synchronized boll maturity suitable for high density planting system (HDPS) released by the University during 2020. This culture was developed at Department of Cotton, TNAU, Coimbatore from the parental hybridization involving Khandwa 2 and LH 2220 followed by pedigree breeding. It matures in 125–135 days and possesses zero monopodia with short sympodial length and is highly suited for high density planting system. It recorded an average seed cotton yield of 2361 kg/ha which is 18.9% increase over the check variety Suraj (National check entry identified for HDPS). Culture TCH 1819 recorded seed cotton yield of 3427 kg/ha which was 21.7% increase over Suraj and 29.0% increase over MCU 7 under rice fallow condition. It recorded a seed cotton yield of 2051 kg/ha which was 13.8% increase over Suraj under summer irrigated conditions and also recorded 1604 kg/ha of seed cotton yield under winter rainfed which was 20.1% increase over the check Suraj.

It was also evaluated in All India Coordinated Cotton Improvement Project trials for two years during 2016–2017 and 2017–2018 across ten locations. It registered seed cotton yield of 1850 kg/ha which was 37.9% increase over Suraj. Adaptive Research Trials (ARTs) were conducted under three different cotton growing seasons *viz.,* rice fallow, winter rainfed and summer irrigated conditions during 2016, 2017 and 2018. It recorded the highest mean seed cotton yield of 4530 kg/ha which was 17.2% increase over the check Suraj under rice fallow condition. It recorded Upper Half Mean Length (UHML) of 27 mm with bundle strength of 26.9 g/tex. It can spin upto 40's counts.

Considering the descriptors of these two varieties, few features can be noticed in common and they are short intermodal length with lesser distance of boll from main stem, bolls of 4–5 g in weight and lesser plant surface coverage of not exceeding 0.25 m^2 ground area and synchronized maturity. Research work undertaken at the Department of Cotton, TNAU during one decade has resulted in identifying these genotypes which could exclusively fit in HDPS. Moreover, research being undertaken in the entire country had resulted in the release of varieties which are meant for HDPS which are detailed (**Table 1**).

2.1.3 Genetics of the traits governing HDPS

Majority of the traits that define a genotype fitting for HDPS include shy branching, 10–15 bolls per plant, boll setting nearer to the main stem, boll of 4–5 g in

Name	Year	Center/State variety Release	Institution
F 2383	2016	State	PAU, Faridkot
CSH 3075	2017	Central	CICR, Sirsa
Cotton CO 15 (TCH 1705)	2018	Central	TNAU, Coimbatore
F 2381	2016	Central	PAU, Faridkot
ARBC 19	2016	Central	UAS, Dharwad
CO 17	2020	State	TNAU, Coimbatore
RS 2818	2020	Central	SKRAU, Sriganganagar
ARBC 1601	2020	Central	UAS, Dharwad
ARBC 1651	2020	Central	UAS, Dharwad
ARBC 1651	2020	Central	UAS, Dharwad
DSC 1651	2020	Central	UAS, Dharwad

Table 1.
Details of cotton varieties released for HDPS (courtesy: Central Institute of Cotton research, Regional Station, Coimbatore).

weight, uniform in size and shape, completion of bursting of all bolls in 3–4 days time, medium to superior medium fiber length with appreciable strength, 120 to 125 days of crop duration for fitting into various cropping programmes. These traits have been extensively studied using the available germplasm and prominent crosses have been effected to identify the genotypes that would fit in HDPS. Studies taken at the Department of Cotton by effecting crosses with genotypes fitting with HDPS and heavy yielders have indicated that crosses CO 17 x CO 14 and TCH 1926 x RB 602 showed high *per se* performance and positive significant *sca* effect for single plant yield. The hybrids C -10-8 x GISV 310 and CO 17 x GISV 310 which involves compact lines showed high *per se* performance, positive significant *sca* affect and positive standard heterosis for single plant yield. The hybrid CO 17 x TCH 1926 had high *per se* performance and positive significant *sca* effect for number of sympodial branches per plant and single plant yield and *per se* performance for number of bolls per plant.

Another study was taken up at the Department of Cotton during 2018–2019 to assess the spectrum of variability realized from differently yielding compact hybrids. Among the 900 observed plants in F2 population, surface covers of 689 plants were recorded as lower than the check (CO 15). The crosses viz., 343–1-1 x CO 14, 343–1-1 x RB 602, TCH 1926 x RAH 1070 and CO 17 x RB 602 were identified as elite combinations as they had more number of individuals whose plant surface was considerably lower than the check (CO 15).

Effect of Okra Leaf Shape in HDPS:

Considering the bigger leaf lamina which is available with CO 17, more pronounced leaf hoppers problem had been observed and breeding research to develop plants with HDPS traits along with okra leaf type had been the tailored programme which was started to function from 2015 to 2016. The okra leaf shape character, on an average in varieties over locations, caused a significant reduction in the incidence of boll rot in comparison with normal leaf cotton [8]. Altering, rather reducing the leaf lamina was significantly associated with an increase in yield, earliness, lint percentage and micronaire value, and a substantial increase in fruiting rate. However, it was also observed that the okra leaf shape had no effect on boll weight and fiber related attributes *viz.,* fiber length, fiber length uniformity, or fiber strength, but with a reduction in fiber elongation and total leaf area.

At present in the Department of Cotton, work initiated on the development of compact plant type with okra leaf shape suitable for HDPS resulted in two F2 populations viz., TCH 1819 x PBH 115 and TCH 1819 x F 2382. Okra-leaf types of the upland cotton have the potential to be competitive to the normal-leaf types in yield and fiber quality, in addition to its potential resistance to insect pests and drought. In cotton, okra leaf type plants confer resistance/non-preference against insect pests. Form these two F2 populations, a total of 85 single plants were selected for compactness with okra leaf. Reciprocal crosses of above two cross combinations were also made. Forwarding these progenies would help in identifying compact plant types with the okra leaf type.

Prominent feature being considered for HDPS is that the genotype must have occupy an area of <0.25 m^2 on the ground and invariably possesses the traits like optimum plant height plant (around 100 cm) with shorter sympodia, shorter inter-modal length with lesser distance of boll from main stem. Albeit the fact that HDPS was worked out for rainfed eco system, it fits well in the irrigated scenario also.

2.2 Agronomic management and interventions

In India, though the area under cultivation of cotton is higher, the seed cotton yield per unit area is very low compared to many other cotton growing countries in the world. The primary factors that attribute for this low realized yield besides the non-availability of choices of genotypes is the low plant population density. Various techniques like maintaining suitable plant density, use of optimum dose of fertilizers, growth regulators etc., are being suggested to overcome these constraints in cotton production. The optimum level of cotton productivity would, however, depends on the plant type being grown. The present day cotton genotypes are of long duration (180–200 days), late maturing, tall growing with spreading nature leading to bushy appearance besides with lesser number of bolls compared to the crop canopy. They also require wide spacing for the expression of the crop resulting in the production of netted canopy resulting in various problems in taking up plant protection measures, machine picking, and inefficiency in trapping of solar energy, physiological efficiency and harvest index.

Because of longer duration, these varieties require more number of pickings, as a result, cost of cotton cultivation upsurge especially owing to manual picking which warrants increased labour and fluctuating prices resulting in lesser realistic income. The availability of labour for clean picking is also a serious constraint. At present, in India, entire cotton is picked manually which is labour intensive and is becoming expensive day by day. About 30 per cent of world cotton being produced in Australia, Israel and USA and other developed countries are picked using machines which were sown as per the requirements of the machine. Such picking through machines would result in "Machine maximum, Man minimum" in cultivating cotton which will not only minimize cost of cultivation, but also reduce the dependency on labour. Machine picking esseentially depends on cultivation of cotton genotypes having short stature, earliness, compactness, sympodial growth habit and synchronous boll opening. Under these circumstances, compact cotton genotypes are ideally suited. They offer great scope for reducing not only row width, but also spacing between the plants in a row.

2.2.1 Ultra narrow row (UNR) planting of cotton

Over the last few decades, many cotton growing countries like China, USA, Australia, Brazil, Uzbekistan and Greece were able to enhance cotton yields by increasing the planting density. The planting geometry, in general adopted varies from 8 to 10 cm distance between plants in a row with the row spacing ranging from 18 to 106 cm, ideal being worked out to 100 cm at our conditions. This planting system is referred as narrow row (NR) if the row-to-row spacing is less than 75 cm and ultra-narrow-row (UNR) if the spacing is less than 45 cm. Currently in India, depending on the local conditions, hybrid cotton is planted at row spacing ranging from 90 to 120 cm and plant spacing ranging from 30 to 90 cm resulting in 15,000 to 25,000 plants/ha. In HDPS, short duration, semi–compact cotton varieties are planted at populations ranging from 1.1 lakh to 2.45 lakh plants/ha by planting at a distance of 45–90 cm between rows depending upon the soil type and growing conditions and 10 cm between plants in a row. It aims to establish around 7–8 plants/m row length. The objective is to limit the boll number to around 10/plant, maximize the number of bolls/unit area and realize high yield in the shortest possible time. If the number of bolls/plant is few, the fruiting window (or flowering period) is short (4–5 weeks) and the plant matures early, producing fibers with good quality.

Ultra narrow row (UNR) cotton production is considered as a potential strategy for reducing production costs by shortening the growing season [9]. By cultivating the genotypes that would fit for UNR, it provides the scope for increasing per unit area of plants *vis-a-vis* the productivity. Being shorter and earlier to mature, these genotypes under UNR provides scope for double cropping and mechanical harvesting. Since the number of bolls are less with uniformity in maturation and bursting, these compact types require few pickings only. This results in savings of labour cost as well as seed cost as it provides farmers an opportunity to reuse the varietal seeds for few sowing seasons.

Adoption of HDPS amicable compact and early maturing cotton varieties offer an alternate to sustainable production at decreased production cost under Indian condition. However, availability of more determinate cultivars, more efficient options of weed control and insect pest management (including transgenics), growth regulations to modify morpho frame, planting and harvesting equipments etc., has made high density cotton planting system popular in several countries. The concept on high density cotton planting, more popularly called Ultra Narrow Row (UNR) cotton was initiated by [10] and this concept has been one of the most researched topics during the last 15 years. Availability of early maturing, compact sympodial plant types with more fruiting bodies closer to the main stem is a prerequisite for successful HDPS.

2.2.2 Planting density

Theoretically, higher planting density ensures earlier crop canopy cover, higher sunlight interception leading to higher and earlier yields at reduced cost. The obvious advantage of this system is earliness [11] since UNR needs less bolls/plant to achieve the same yield as conventional cotton and the crop does not have to maintain the late formed bolls till maturity. In general, it was observed that lower plant densities produced higher values of growth and yield attributes per plant, but yield per u--nit area was also higher with higher plant densities [12–14]. Fertilizer and pest management are important consideration for increased yields under high density planting system. Changes in plant density modifies the microclimate and this may alter the incidence of pests and diseases as well [15]. Studies taken up using the genotypes AKH 081,Suraj and NH 615 under HDPS revealed that these entries could yield better at 60 x10 cm spacing under medium depth soils with a planting density of 1.66 lakh plants per hectare on broad bed furrow (BBF) with 125 per cent of recommended fertilizers (75:37.5:37.5 NPK + 2.5 Zn kg/ha) along with a foliar spray of 1% urea and 1% magnesium sulphate at boll development stage [16].

2.2.3 Growth manipulation

The very purpose of evolving genotypes suitable for HDPS would be achieved only by manipulation of row spacing, plant density and the spatial arrangements of cotton plants for obtaining higher yields. The most commonly tested plant densities range from 5 to 15 plants per sq. m [17] resulting in a population of 50,000 to 150,000 plants per ha. The UNR cotton plants produce less number of bolls per plant than conventional cotton but retain a higher percentage of the total number of good opened bolls per unit area in the first sympodial position and a lower percentage in the second position [18]. The other advantages include better light interception, efficient leaf area development and early canopy closure which shades out the weeds and reduce their competitiveness [19]. The early maturity in soils that do not support excessive vegetative growth [20] can make this system ideal for shallow to medium soils under rainfed condition where conventional late maturity hybrids experience terminal drought.

Cotton growth must be regulated and eventually terminated by chemical means, due to the plants' intrinsic indeterminate growth habit. Plant growth retardants are natural or synthetic organic compounds that control or modify one or more physiological events in plants. These synthetic compounds are widely used in cotton for reducing plant height. The plant growth retardants affect many physiological functions in plants. The crop growth regulator Mepiquat Chloride (MC) is commonly used in cotton production in China and elsewhere to maximize cotton yield and fiber quality [21, 22]. The application of MC increases leaf thickness, reduces leaf area [23], shortens internodes [24] and decreases plant height [25], and thus results in a more compact plant architecture [26] which had been witnessed in the CO 17 culture as well (**Figure 2**).

Figure 2.
Application of Mepiquat chloride in cotton variety CO 17.

Modification of cotton structure increases the light interception in the middle part of the canopy [27]. In addition, Light Use Efficiency (LUE) of cotton is increased by MC application [28]. Furthermore, cotton canopy structure is affected by population density [29] and practices such as wheat–cotton intercropping [30] which influence the crop light interception and fruit formation, thereby biomass growth and yield.

High population densities increase leaf area index (LAI) but reduces the individual leaf area [29]. Like most species, cotton plant height increases with population density [31]. Field experiments raised with CO 17 wherein cotton plant structure was obviously affected by MC and plant density. As MC could bring in changes in the architecture of the applied plant resulting structural changes, it leads to a challenge in maintaining the cotton plant's architecture suiting to the mechanized cultivation. Application of MC is essentially responsible for controlling cell elongation and shoot and stem growth [32]. When plant growth retardants are applied to plants, internodes become shorter and leaves become thicker and greener which leads to altered plant morphology and altered assimilate partitioning resulting in reduced plant growth. The response of plants to PGR applications can differ with plant growth stage, rates of application, and environmental conditions during the applications [33]. Cotton producers and researchers have, therefore, used plant growth retardants as a means to manage the balance between vegetative and reproductive growth for efficient cotton production. But research on application of growth retardants in conjunction high density planting will pave way for synchronized maturity of the crop with uniform plant height that may help in harvesting of seed cotton mechanically at large scale level. This research is at its nascent level in India.

Mepiquat Chloride (1,1-dimethyl-piperidinium Chloride), a plant growth regulator is widely used to manage cotton structure, regulate plant development and hasten maturity under high plating densities [34]. Although plant growth regulators have been thoroughly widely tested in cotton in India, specific recommendations regarding their dose and timing for modifying the architecture at high planting densities are yet to be arrived for adoption on a holistic perspective. Reduction in plant height, decrease in height/node ratio, an increase in boll weight and a delay in maturity with the application of growth regulators were observed with non-significant effect on yield. Application of Mepiquat Chloride reduced the leaf area and increased the number of bolls per unit area at high plant density. It also helped in retention of bolls on lower sympodia and increased the synchrony of boll maturation [29].

However, the effect of Mepiquat Chloride on cotton is affected by environmental conditions, particularly temperature [35]. Studies taken up at the Department of Cotton indicated the differential response of cultures and its performance across centres. At Coimbatore, there was a variety dependent response to Mepiquat Chloride application @ 75 g ai/ha in three splits on 45, 60 and 75 DAS in winter irrigated cotton planted at 45 x 15 cm spacing and the effect was more pronounced in CO 17 (**Figure 3**).

There was a reduction in plant height, sympodial length and LAI and an enhanced the number of burst boll/sq. m leading to an increase in yield at Coimbatore. Across the cultivars, application of Mepiquat Chloride increased seed cotton yield from 1330 kg/ha to 1530 kg/ha. Interaction effect of cultivars and application of Mepiquat Chloride was significant. Taller cultivars namely TCH 1608 and TCH 1705 (CO 15) benefitted more from the application of Mepiquat Chloride compared to the other cultivars having a compact growth habit. Cultivars with a more indeterminate growth habit responded more positively to Mepiquat Chloride application [36]. There is a need for detailed investigations on this aspect before any recommendations are given.

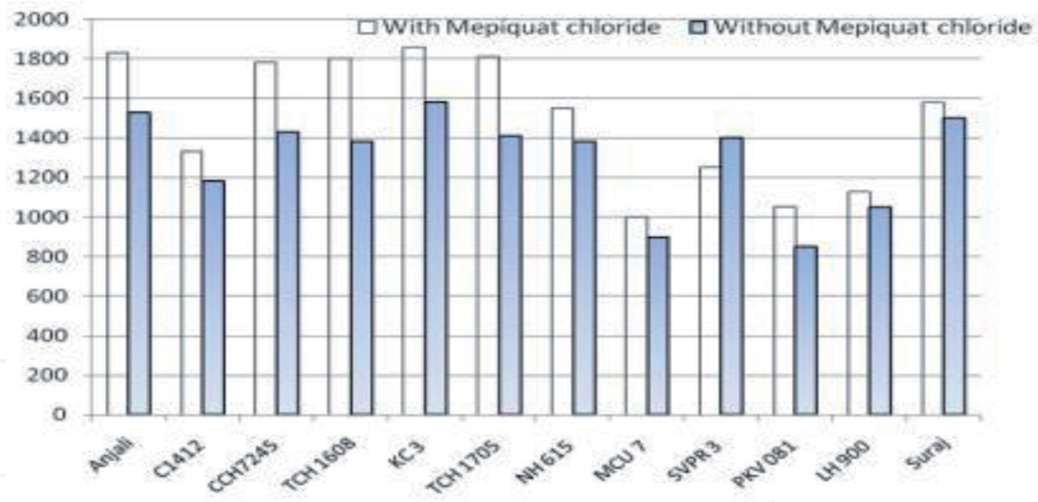

Figure 3.
Effect of Mepiquat chloride on cotton varieties.

2.2.4 Effect of Mepiquat chloride application on seed cotton yield in different genotypes

2.2.4.1 Defoliation

Arresting the growth of the cotton plant followed by the defoliation of leaves at the physiological maturity stage of the plant would facilitate in harvesting the fully opened bolls through mechanical instruments. As we know that killing and fixation of specimen are required for having cytological observations by employing a mix of acid and alcohol, the two events namely growth arrest and defoliation have to occur for effecting the harvest of bolls in cotton. Thus, cotton defoliation requires the application of certain chemicals to help prepare a cotton crop for harvest. Benefits of proper cotton defoliation include: reduction of the main sources of stain and trash (leaves), increased harvest efficiency, quicker drying of dew, potential for increased boll opening and a reduction of boll rots. As a cotton plant matures, a physiological process takes place which separates the living tissue near the leaf petiole called the abscission zone. A regulated enzyme activity under the influence of plant hormones making the leaf to fall through the creation of abscission zone is the need.

Two types of defoliants, by and large are available. A herbicidal defoliant can be used to cause injury to the leaf, upset the hormone balance resulting in the abscission process and finally the leaf drop. The other one is the application of a hormonal defoliant which increases ethylene synthesis in a plant causing the leaves to fall off. Correct application rates are important, especially with herbicidal defoliants, as over application can cause the leaf to die before the abscission process, resulting in "stuck" leaves. Conversely, when too little defoliant is applied, the abscission process may not begin, resulting in no leaf defoliation.

2.2.4.2 Factors affecting defoliation

When applying a defoliant or desiccant or boll opener, many factors must be taken into consideration for successful application. Best results from an application occur when the factors like the type of cotton being grown, its duration, weather/climatic conditions, soil conditions, availability of inorganic fertilizers to the plant, bursting of bolls, water availability to the plants, spacing between the rows and plants, etc. are taken into consideration.

Figure 4.
Application of Mepiquat chloride and defoliant in CO 17.

Studies taken up at TNAU utilizing the application of MC and Defoliant indicated that the combination of application of MC 50 g ai/ha at 45 and 65 DAS and Dropp ultra (Thidiazuron and Diuron) @ 200 ml/ha at maturity resulted in 90 per cent defoliation in CO 17 and prepared the crop for harvest by 135 days. This is in the preliminary stage of testing and would be tested in the years to come to arrive at a comprehensive package (**Figure 4**).

2.3 Pests management

2.3.1 International level

Because of various types of insects that attack the cotton crop, especially from the young seedlings (leaf miner, gall formers etc.) till the crop attains maturity (various borers, weevils etc.), cotton crop receives excessive rounds of pesticides spray. This results in excessive consumption of plant protection products. Many research are being taken up towards developing holistic packages including chemical, physical, biological and IPM techniques to contain these pests. Cotton is under cultivation in 69 countries and the production had exceeded 20 million tones of lint in the recent years where the cultivable area spread on 30–35 million hectares. In spite of improvement attained through chemical control strategies, harvest losses remain very high which dwindles around 30% [37, 38]. Occurrence of varied insects in the cotton system during varied crop growth stages makes it as an experimental model crop for devising plant protection strategies to be practiced under various agronomic conditions.

Albeit very many newer molecules are synthesized and tested to contain the pests, harvest losses remained high. All the pest management strategies aims to keep the pest population below the Economic Threshold Level (ETL) which is normally attained by having a judicious mix of appropriate methodologies. Total pest management is achievable only when the pest prefers a single crop, say cotton and there are no significant alternate hosts available in the vicinity of the crop system. However, the application of IPM principles greatly depends on the concept of an intervention threshold and the limitations of many of the specific non-chemical techniques proposed but the application of IPM modules/principles have the advantage of taking into consideration the full pest complex in a cropping system [37].

Biological control by introducing beneficial arthropods has not been notably successful in all the crop based systems, which is true for cotton also. This is because of the difficulty in identifying and acclimatizing the predators/parasites, developing a bunch of beneficial organisms capable of responding effectively, the nature of the crop grown and the disrupting effects of chemical control measures directed against the remaining pests [39]. More benefit is to be obtained from the active conservation of the indigenous fauna of beneficial organisms. In spite of an increased general environmental awareness, the practice of using insecticides could not be resisted as pests evolve resistance to pesticides and a combinatory approach to contain the pest is the need of the hour.

Suggested strategies were adopted throughout the growing season in Australia. Primary target of reducing the pesticides consumption in cotton ecosystem was brought out by the introduction of Bt gene engineered cotton hybrids which allows the co-existence of natural enemies. However, the least affected species by the Bt toxins, the sucking pests took a prominent place in cotton based production system displacing the vegetative and fruit feeding caterpillars as key pests of Bt cotton [40]. The spatio-temporal dimension of natural population regulatory factors has led to changes in agricultural practices and production systems. In cotton, for example, production systems maintaining a permanent ground cover, are having increasing success. Many a times, farmers leave the crop in the field after harvest of bolls alone, especially for getting a second flush with the onset of rains resulting in enhanced outbreak. Intercropping and trap cropping have been favorable to the maintenance of beneficial arthropod complexes and unfavorable to the growth of pest populations. Thus for having an effective control over the pests, a changed strategy towards a total systems approach, characterized by a movement from a paradigm of pest control field-by-field, through farm-by-farm and agroecosystem-by-agroecosystem, to a landscape by landscape approach is required as reported by [38].

The rich and diverse insect fauna found in cotton harbors more than one thousand species. However, very few are designated as significant potential pests. These pests damage the flowers and fruiting bodies or consumes the leaves or mine the leaves and sucks the juice of the leaves of young plants. Some of them are monophagous species, restricted to the genus *Gossypium* (*Anthonomus*, *Diaparopsis*) while oligophagous feeding on plants in the family of Malvaceae and closely related families (*Pectinophora*, *Dysdercus*, *Earias*) or polyphagous feeding behavior (*Helicoverpa*, *Heliothis*, *Cryptophlebia*, *Spodoptera*, *Helopeltis*) were also reported. The heliothine lepidopteran species complex (*Heliothis virescens*, *Helicoverpa armigera*, *Helicoverpa zea*) is considered as the most dangerous, found attacking numerous other cultivated plants which are often associated with cotton in a range of cropping systems [41]. However, as indicated earlier, the leaf hoppers and white fly are becoming a menace nowadays.

2.3.2 National level

Cultivating cotton by adopting closer spacing with the available cultivars and with those having short branches was conceived and implemented in India since sixties of the 20th century. Visits, exposures, dialogs and discussions could improvise the learning and the team's visit to Brazil had sown the idea of researching on High Density Planting System (HDPS) and the churned idea was implemented by reorienting research through All India Coordinated Cotton Improvement Project (AICCIP) and through other schemes like Technology Mission of Cotton (TMC) or National Food Security Mission (NFSM) in India [42]. It is reiterated that the success of HDPS at varied locations solely depends on the availability of genotypes, appropriate spacing and nutrition for adopting more plants per hectare to achieve more productivity per unit area and sound pest management criteria. This necessitates the evaluation of available genotypes in varied spacing and nutrition level to the incidence of insect pests. As farmers tend to grow more Bt which are normally of spreading in nature, evaluation of both Bt and not Bt compact genotypes for their suitability to HDPS is the need of the hour. The adoption of HDPS along with better genotype and fertilizer management is a viable approach to break the current stagnation of yield.

More the synthetic fertilizer application, especially nitrogen (N) fertilizer, more the serious insect herbivores occurrence and crop damage from these insects by reducing plant resistance, the concept which has been conceived clearly [43, 44]. Reducing fertilizer applications can reduce the production costs for cotton growers, as well as nitrogen (N) leaching into the soil and contamination of surface and ground water, but altered N fertilization may also affect pests and their natural enemies [45]. Occurrence of insects and their abundance are heavily dependent on the micro climate available in the system which is primarily based on the biomass production by the plants and their nearness (spacing). Hence, it is utmost important to study the pest dynamics under closer spacings as well as increased levels of nitrogen applications.

A study taken up using GSHV-01/1338 and GBHV-164 genotypes among others revealed their ability as promising genotypes of the region suited to high density planting system due to its compact nature [42]. At two levels of closer spacings (60x15 and 45x15 cm) against the normal spacing of 120x45 cm along with two increased level of nitrogen application (i.e. 125 and 150% of RDN), these two genotypes performed better. The studies were carried out in factorial randomized block design *Kharif* 2013–2014. Closer spacings (45x15 and 60x15 cm) attracted more thrips as compared to the recommended spacing (120x45 cm). The mean population of thrips was found significantly high on GBHV-164 than GSHV-01/1338. Higher dose of nitrogen application on crop (125 and 150% RDN) attracted more thrips as compared to 100 per cent recommended dose of nitrogen (RDN).

[46] by quoting a field experiment that was conducted to study the mean incidence of major cotton insect pests during two consecutive seasons *i.e*. during *kharif*, 2010–2011 and 2011–2012 at CICR, Nagpur under high density planting system (HDPS) using different genotypes of *G. hirsutum* with different spacings indicated that pest incidence was not altered by closer spacing. The main objectives of the work was to identify lines of *G. hirsutum* which have less infestation of major insect pests under HDPS system and to investigate whether the incidence is influenced by plant density. In 2010–2011, the minimum mean population of leafhopper was observed in NISC-50 (1.82 nymphs / 3 leaves /plant) which was grown at a spacing of 45x13.5 cm followed by PKV-0811 (1.91 nymphs /3 leaves/plant) grown at a spacing of 45x13.5 cm and these genotypes are significantly superior over the others. The injury grade was I in both NISC-50 and PKV-081 genotypes. The mean per cent square damage was low in CNH-120 MB (2.76%) followed by PKV-081 (3.82%), both being statistically on par with each other and significantly superior over other genotypes. The mean pink bollworm population was low on PKV-081 (2.53 larvae/25 green bolls). The lowest per cent locule damage due to pink boll worm was noticed on PKV-081 (8.48%). However, the performance of genotypes and geometry against all the insect pests in 2011–2012 was not significantly different leading to a conclusion that pest incidence was not altered by closer spacing.

[47] reported in a study undertaken during 2015–2016 on High density planting demonstrations (50) which were taken up in farmers' fields at varied close spacings (75x10 and 90x10cm) with available compact genotypes (Suraj and G.Cot.16) compared to normal spacing (120x45 cm) under Insecticide Resistance Management (IRM) umbrella in rainfed regions of Bharuch district. Aphids, thrips and leafhopper were found above ETL whereas whitefly and mealybug were found below ETL. The mean larval population of pink bollworm was 4.41 and 3.14 larvae/20 green bolls in Suraj and G.Cot.16 spaced at closed spacings respectively. The pink bollworm population was 2.51 and 2.68 larvae/20 green bolls in Bt-IRM and non IRM

plots respectively. Suraj variety spaced at 75x10 and 90x10 cm required 4.21 and 3.33 sprays and G.Cot.16 spaced at 75x10 and 90x10 cm required 4.40 and 3.60 sprays against sucking pests and 2.37 and 2.38 and 3.20 and 2.40 sprays against bollworms respectively as against 5.00 and 5.60 sprays against sucking pests and 2.00 and 3.80 sprays against bollworms in Bt-IRM and Bt-Non IRM cotton respectively. These results suggest the need for excessive sprays in ultra closer spacing than the normal closer spacing for both the cultivars. The net return was found higher in G.Cot.16 HDPS at both the spacing (Rs. 22,966 and 17,456/acre) than the Suraj HDPS (Rs. 16,461 and 8235/acre). The net return for Bt-IRM farmers was higher (Rs.21527/acre) than non IRM-Bt farmers (Rs. 17,919/acre). Thus, it has been concluded that HDPS offer viable option to increase productivity especially under rainfed region.

The cotton crop is attacked by 1326 species of insect pests throughout the world, of which about 130 different species of insects and mites found to devour cotton at different stages of crop growth in India. Among the bollworms, pink bollworm assumed major pest status in recent past [48]. The pink bollworm, *Pectinophora gossypiella* (Saunders), a pest which received more attention in almost all the cotton growing states of India (except Tamil Nadu as of now), is identified as the most destructive pest of cotton and causes 2.8 to 61.9 per cent loss in seed cotton yield, 2.1 to 47.1 per cent loss in oil content and 10.7 to 59.2 per cent loss in normal opening of bolls [49]. Locule damage was noted to an extent of 55 per cent and 35–90 per cent reduction in seed cotton yield has been reported by [50, 51] estimated the yield loss to an extent of 6525 MT annually.

Losses caused by pests vary by 10–30% depending on the intrinsic genetic factors and its rigidity in expressing the inherent resistance. Pests are supposed to evolve in a short and strategic cycle to circumvent the problems being arisen and judicious use of insecticides along with physical, biological control methods is the need of the hour. Ignoring pests can lead to complete crop failure. In the overall crop protection program under the National Agricultural Policy, The Government's IPM is a time-tested, eco-friendly approach, socially acceptable and economically viable that is widely accepted across the country. Appropriate control measures should be taken when insect populations cross the ETL [52].

2.4 Diseases management

High density planting which entails closer planting may have every chance of microclimate getting altered due to which the propensity of infectious diseases in cotton may also vary. The high density planting in cotton is a recent phenomena which opened avenues for research in various domains including plant pathology. The plant pathologists have been trying to understand the nexus between the incidence of various cotton diseases and the change in microclimate of the plant coupled with external atmosphere [53, 54].

The life cycle of pathogens is amenable for changes in line with the changes in plant canopy and the microclimate mediated through weather parameters. Space between plants and rows is bound to have a say in the mode of dispersal, the intensity of infection and the production of secondary inoculum of plant pathogens. Cotton, being a commercial crop, is no exception to this phenomena of infection and the high density planting in cotton need to be carefully contemplated taking into account the changed plant geometry and the corresponding incidence of cotton diseases. Despite the research on influence of high density planting in cotton on the incidence of diseases is in the nascent stage, an attempt has been made to take stock of striking developments in the management of important cotton diseases in the succeeding pages.

The major diseases of cotton which are prevalent in most part of the cotton growing countries in the world were reported to inflict a damage ranging from 10 to 30% and it may be more when favorable conditions prevail for the spread of the pathogens which culminates in cotton farmers spending huge cost to keep the biotic stress under control [55].

Fungal diseases are predominant in cotton followed by very few bacterial and viral diseases. The prominent bacterial disease which inflict major damage in cotton crop is bacterial blight, caused by *Xanthomonas citri* pv. *malvacearum* [56]. Abundant literature is available on major fungal diseases of cotton namely *Fusarium* wilt caused by *Fusarium oxysporum* f. sp. *vasinfectum*, *Verticillium* wilt caused by *Verticillium dahliae*, anthracnose caused by *Colletotrichum gossypii*, Ramularia gray mildew caused by *Mycosphaerella areola*, root rots caused by *Rhizoctonia solani* and *R. bataticola*, leaf blight caused by *Alternaria macrospora* and leaf spot caused by *Cercospora gossypina* [57–62]. The cotton leaf curl disease is the only virus disease documented in cotton which belongs to the genus Begomovirus and transmitted by insect vectors [63].

Plethora of studies were conducted for the management of cotton diseases which reported solitary or combination of management practices to control them. Besides chemical control, significant research work has been carried out on the biological control of cotton diseases [64–67]. Similarly, there were prominent studies on use of plant extracts [68–70] and essential oil [71, 72] for the management of cotton diseases. Cultural methods [73] and organic amendments [74] also form part of the strategy to control cotton diseases.

In the recent past, several research studies have documented the efficacy of Endophytic bacteria [75] in suppressing the incidence of cotton diseases. Molecular level studies namely transcriptomic, proteomic and metabolomic studies [76–78] and studies on gene editing [79] were on the rise for the past two decades. As there are several methods and molecules have been designed for effecting the control of diseases, their role in containing the diseases that occur under HDPS is in infant stage as the genotypes which have been evaluated at Coimbatore were not found to have adequate disease expressions under HDPS.

2.4.1 Soil borne diseases

Soil borne fungal diseases of cotton namely damping off, root rot and wilt have been reported to cause extensive damage in cotton crop. Juxtaposing chemical control with biological method, the latter was found to be effective which is evidenced from the finding of [80–82] who reported that the combined application of *T. harzianum* and *P. lilacinus* showed the best result by inhibiting the growth of pathogen than alone. A recent study of [83] reported that Trichodel®, based on *Trichoderma* spp., reduced the incidence and severity of wilt caused by *F. oxysporum* f. sp. *vasinfectum*. Besides, a score of agronomic practices namely fine tilth of the soil, adjusting sowing season, crop rotation, soil solarization, amending soil for altering pH of the soil and use of resistant varieties have been reported to reduce the incidence of soil borne diseases. Biological control of *V. dahliae* in cotton with a mixture of lignin and *Trichoderma viride* [84] has been reported. Thus, biological control of soil borne diseases is the viable option which had been arrived by various authors in the normal cotton growing situations. However, the same might hold good under HDPS also.

2.4.2 Foliar diseases

Among the foliar diseases, Alternaria leaf spot, gray mildew, boll rot, rust, anthracnose and bacterial leaf blight were reported in cotton and they were reported to inflict damage significantly. The chemical fungicides mancozeb (0.3%), propiconazole (0.1%), propineb (0.3%) were found more effective against

Alternaria macrospora, propiconazole (0.1%) and copper oxychloride (0.25%) against *Myrothecium roridum* [85, 86]. Moreover, a decadal analysis of *Alternaria* occurrence among the various genotypes at Coimbatore indicated that Bunny Bt cotton, NCEHBT, Dhannu BGII and 1037 BGII genotypes were found to be more susceptible and the disease incidence ranged from 0.5 to 10.53 PDI compared to the types which are resistant/field tolerant. In addition, the sowing taken up during 29th–30th Standard Meteorological Week (SMW) resulted in lesser incidence of the disease irrespective of the cultures evaluated [87].

Among the biocontrol agents studied, *Pseudomonas fluorescens* strains and *Bacillus subtilis* and the botanicals derived from *Azadirachata indica*, *Lantana camera*, *Calotropis procera*, *Ocimum sanctum*, *Allium cepa* and *Allium sativum* have been reported to significantly reduce the mycelial growth of the pathogenic fungus [88]. The methanol extracts of *Polyalthia longifolia* and *Terminalia chebula* and chloroform extract of *Zingiber officinale*, *Datura alba*, *Moringa olifera*, *Azadirachta indica* and *Syzgyium cumini* have showed significant biological control of cotton bacterial blight in greenhouses and in fields [89, 90]. This indicates that principles available in various plants are having sizable influence in containing the growth of disease causing micro organisms.

2.4.3 Viral diseases

Among the viral diseases infecting cotton, cotton leaf curl virus and tobacco streak virus are important. The TSV disease was reported to be spread through mechanical means, infected seeds and through thrips species. Parthenium, a widely distributed and symptom less carrier of TSV, plays a major role in perpetuation and spread of the disease [91–95].

A study carried out by [96] uncovered the application of *Bacillus* species which possess diverse anti microbial peptide (AMP) genes which are responsible for the biosynthesis of antibiotics like iturin, bacilysin, bacillomycin, fengycin, surfactin, mersacidin, ericin, subtilin, subtilosin, and mycosubtilin in curtailing the infection of TSV. Genetic Engineering studies to evolve transgenic cotton using an antisense RNA approach [97] could be a potential option for managing the disease. Interestingly, transgenic cotton plants that over express miR166 also show potential in reducing *Bemisia tabaci* populations and, more importantly, the spread of whitely transmitted plant viruses [98, 99]. Gene editing technology *i.e.,* CRISPR/Cas9 system has recently been used to confer molecular immunity against several eukaryotic viruses, including cotton DNA geminiviruses [100].

3. Conclusion and futuristic approaches

Though evolving a suitable ideotype remains the basics of successful adoption of any HDPS, the evolved genotype's suitability to the various management practices results in its adoptability. Nowadays, many of the farmers are going for Bt cotton and that too under rainfed situations. Considering this as a backdrop, the genotypes under development either through conventional method employing crossing between the selected genotypes and progeny selection or mutation breeding or selection of desirable genotypes from the pre-bred materials or by any of the molecular methods must fit for one or more situations as described below.

- Considering the occurrence of weeds in both irrigated and rainfed systems, the HDPS genotype must possess inherent herbicide tolerant/resistant behavior either through inheritance or through infusion using biotechnological tools.

- Transplanting of cotton have been identified as one of the viable option for maintaining the sufficient plant population. Preliminary studies taken up at the Department of Cotton also indicated the survival of 15–20 days old seedlings of CO 17 variety upto 25 per cent. However, the growth observed in the transplanted plants was stunted. Studies taken up by [101] indicated that date of sowing, age of seedling for transplanting bears a relationship on the seed cotton yield. Moreover, Bt cotton sown directly or through tray nursery or through polythene nursery of varied duration had varied impact on seed cotton yield. Polythene nursery with 3 weeks old seedlings upon transplanting could result in a yield of 4727 kg/ha. Thus, clear cut studies on the evolved genotype for its suitability to transplanting through any one of the methods are required.

- It has been observed that cotton plants raised under dense paired sowing produced the highest seed cotton yield and water use efficiency [102]. Hence, the evolved genotypes need to be tested for its water use efficiency under fertigation studies which is the need of the hour. Preliminary experiments conducted with CO 17 in this regard with varied level of population and varied nutrient levels under drip fertigation revealed that spacing 75 cm × 10 cm spacing coupled with STCR based drip fertigation recorded net return of Rs. 131,302/ha.

- Another interesting observation made by [103] was weed density and weed dry matter production were lesser at closer spacing of 30 x 30 and 45 x 30 cm as compared to widely spaced cotton. Though this is to be taken care of, more closer spacing would attract pest and diseases and hence an ideal spacing has to be arrived for evolved genotypes.

- The evolved genotype (preferably as a variety) must have an yield advantage and increased per day productivity compared to the *Bt* hybrids which are normally bred and released by the private companies.

- It has to be ascertained, that by all means, the evolved genotype should contain the deregulated gene/QTLs conferring resistance to bollworms or genes that are of native origin which are freely available. This is because that the non Bt cotton variety F 2383 released by Punjab Agricultural University during 2015 for cultivation under HDPS had the susceptibility to boll worms besides smaller boll size [104].

- In USA, it took 30 years to achieve 100 per cent mechanization, while it was 45 years in Brazil. Turkey reached 75 per cent mechanization in 15 years and China took 20 years to reach 15 per cent mechanization. However, in India, as seen, harvesting is completely labour oriented and all the activities need to be mechanized [105]. It has been also indicated that the mechanical picking with single row picker under HDPS provided 25–40 per cent yield increase compared to the farmer's practice. Preliminary studies done in this aspect in the Department of Cotton with CO 17 variety indicated that mechanizing the sowing, spraying, weeding operations alone had resulted in a savings of Rs. 51,000(698 US $).

- This gives a clear message that mechanizing cotton cultivation is of essential one and the evolved genotype must fit for mechanized cultivation in India.

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Conflict of interest

The authors declare no conflict of interest.

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